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Environmental implications of food loss probability in packaging design

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ABSTRACT

In this paper, a new perspective of food packaging design is proposed by using the Life Cycle Assessment (LCA) approach, in which shelf life and food loss probability were taken into account. The study focused on twenty-four scenarios of packaging of a ripened cheese obtained from sheep milk, in order to analyze the environmental implications of different packaging systems in terms of potential food loss. The aim is to provide an eco-indicator able to quantify the environmental indirect effects related to the different choices in the food packaging. Results highlighted that, by considering only the direct inputs and outputs of the packaging system, thinner and recyclable packaging materials sealed in air are more sustainable from an environmental point of view. On the contrary, if indirect effects of food loss probability are also taken into account (e.g. production and transport of cheese in order to reconstruct the stockpile), multilayer systems under modified headspace conditions are preferred packaging solutions. This is consequence of the fact that cheese production brings about high environmental impacts if compared to the other phases of the life cycle, therefore, the environmental implications of the choices adopted for the packaging phase are more affected from the capacity of reducing food losses than from the production and disposing of packaging materials.

1. Introduction

Product shelf life is defined as the period of time during which the quality of the packaged food remains acceptable. This period may range from a few days to more than one year because each category food has its specificity in quality kinetic deterioration. For this reason, the packaging must have properties to assure that the desired shelf life is not compromised (Kilkast & Subramaniam, 2000; da Cruz, Faria, & Van Dender, 2007; Del Nobile, 2001; Del Nobile, Licciardello, Scrocco, Muratore, & Zappa, 2007). There are numerous variables that can play a significant role in establishing package performance, such as the initial food quality, the processing operations, the size and shape of package. Considering the importance of packaging in determining product shelf life, the correct approach allows considering on the same level of importance the product development and its packaging system (Cleland, 1996). Packaging design has gained great importance over the last decades due to the numerous available packaging options that offer various alternatives for cost and time reduction (Rodriguez-Aguilera & Oliveira, 2009). On the other hand, it is necessary to consider that even though packaging plays an important role in food preservation (Conte, Scrocco, Brescia, & Del Nobile, 2009), it also represents an environmental issue, being considered one of the most wastes of industrialized countries. The main criteria taken into account for packaging optimization have been referred to the balance between packaging performance, in terms of shelf life, and its costs, without considering the environmental implications. Generally, materials that assure long shelf life show a higher impact on the environment (Luz, 2012; Williams, Wikström, & Löfgren, 2008). However, in the management system, packaging has been individuated as one of the nine causes able to reduce losses in the supplier–retailer interface (Mena, Adenso-Diaz, & Yurt, 2011).

In fact, the environmental assessment of food packaging focused only on the materials and their recyclability (Harding, Dennis, von Blottnitz, & Harrison, 2007), without considering the overall impacts caused by food losses (i.e. food products that cannot be distributed because expired). If the evaluation aims to investigate also the indirect environmental implications, the best packaging system should balance between the environmental impact of the package itself and the impact deriving from the potential loss of the packaged product, which in turn is strictly related to its shelf life (McMillin, 2008; Williams & Wikström, 2011). As a matter of fact, shelf life extension plays a very important role on food losses reduction by increasing the usability of food (Marsh & Bugusu, 2007) and also allowing their distribution on a larger scale (Luz, 2012). For example, the capability of the active packaging to prolong the shelf life and reduce food losses has already been widely recognized by the packaging and food industry (Williams & Wikström, 2011; Wikström & Williams, 2010). In the same context, Zhang, Hortal, and Dobón (2015) provided a link between food loss saving and the food packaging system's overall environmental performance. The authors compared the eco-profiles of beef using conventional modified atmosphere packaging (MAP) and novel MAP (active coating), demonstrating

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that using active packaging solution a substantial reduction of beef losses at the retail of market could potentially be realized and a more significant food loss reduction could be expected at household level. Nevertheless the numerous efforts to study the environmental impact of food, a real quantification of the environmental indirect effects related to the different choices in food packaging is still lacking. This is mainly due to the lack of a direct relationship between food loss probability and packaged food shelf life. In addition, it is also worth considering that in the coming years, consumer preference for fresh products ready to eat, which reduce time for preparation and cooking (Lundqvist, de Fraiture, & Molden, 2008) could further provoke an increasing amount of food losses.

LCA considers the environmental impacts of all the phases of the life cycle of a product, from raw materials through production, use and finally to waste management (Russell, Ekvall, & Baumann, 2005; Baumann & Tillman, 2004; Guinée et al., 2001). This methodology was standardized according to the ISO 14040 (2006) and ISO 14044 (2006) standards, in four steps: goals and scope definition, inventory analysis, impact assessment and interpretation (ISO 14040, 2006 and ISO 14044, 2006). Despite of the fact that LCA methodology was traditionally used to assess the environmental performance of food products (Roy et al., 2009; Schau & Fet, 2008; Mattson & Sonesson, 2003), it is also applied to study food waste and more recently the food losses (Laurent et al., 2014; Kim & Kim, 2010; Lundie & Peters, 2005).

In this study, the case of "Canestrato di Moliterno" cheese was used to simulate the effects of various packaging systems on both product shelf life and food loss probability, and performing an eco-indicator able to highlight the environmental indirect implications related to the potential food loss. In the perspective to balance convenience, protection, shelf life and environmental impact of the package (Verghese, Lewis, Lockrey, & Williams, 2013), which also account for the environmental indirect effects, the current work aims to propose a packaging design that takes into account the environmental impact of both packaging (in terms of materials and technology) and food loss, by using the Life Cycle Assessment (LCA). In particular, three different equations between food loss probability and packaged food shelf life are proposed to quantitatively determine the environmental indirect effects.

2. Materials and methods

2.1. LCA approach

According to the ISO 14040 and 14044 standards, and the guidance provided by the ILCD — International Reference Life Cycle Data System (EC-JRC — Institute for Environment and Sustainability, 2010) the LCA methodology was applied by following two approaches:

— The first one follows the rules of an *Attributional approach* (AA), in order to obtain information about the impacts of the adoption of the different packaging solutions, by considering only the phase of packaging, including the production and disposal of packaging materials.
— The second one is a new approach similar to a *Consequential approach* (CA), because it aims to gather information about the consequences of decisions in packaging choices. Despite of the fact that no large-scale change could be occurred, the CA that we used wants to investigate the environmental implications of decisions in changes of the plastic films and gaseous atmospheres. Both inside effects (production and disposal of plastic materials) and outside effects (shelf-life and food losses) were examined.

For both the approaches, the Functional unit (FU) was set at 100 g of packaged portioned sheep's milk cheese. As concerning the reference flow, for AA it was set at the amount of input and output linked to FU. As for the CA the reference flow refers not only to the input and output linked to the production, packaging and distribution of the FU, but also all flows needed to the stockpile reconstruction as consequence of food losses (production of other cheese and transport).

As for the system boundaries, the differences between the two approaches are represented in Fig. 1. In order to highlight the environmental indirect effects of the different shelf life in terms of food losses, the following assumptions were established:

— The packaging with the longest shelf life entails the lowest food loss, which was set to 8% (Lebersorger & Schneider, 2011);
— The longest shelf life is the time scale in which the supply of cheese must be guaranteed;
— Three trends over time of food losses were analyzed: sigmoid, first-order function and straight line;
— Within the settled time scale, the loss of packaged cheese with shorter shelf life entails the reconstruction of the stockpile, and so, the production and transportation of other packaged cheese.

2.2. Life cycle inventory

The life cycle inventory was performed according to the Production Regulation of the PDO "Canestrato di Moliterno" (Table 1). The geographical context is referred to the two provinces of the Basilicata region (Matera and Potenza, South of Italy), in which this production is allowed. As for the sheep breeding phase the following assumptions were considered:

- an average daily milk production per head of sheep 0.5 l;
- a period of milk production of 180 days;
- an average production of wool per sheep per year of 3 kg;
- an average production of lamb (live weight) per year of 15.75 kg.

According to the assumption listed above, an allocation procedure was performed by considering the mass; the percentages attributed to main product (milk) and co-products are the following:

- Sheep milk 83%;
- Lamb 14%;
- Wool 3%.

The co-product lamb and wool are considered as input for other processes, while manure was modeled as waste spread in the soil.

Data referred to sea salt and health products were excluded from the analysis, due to the fact they are not available from databases or scientific literature; furthermore, as for medicines, they are employed

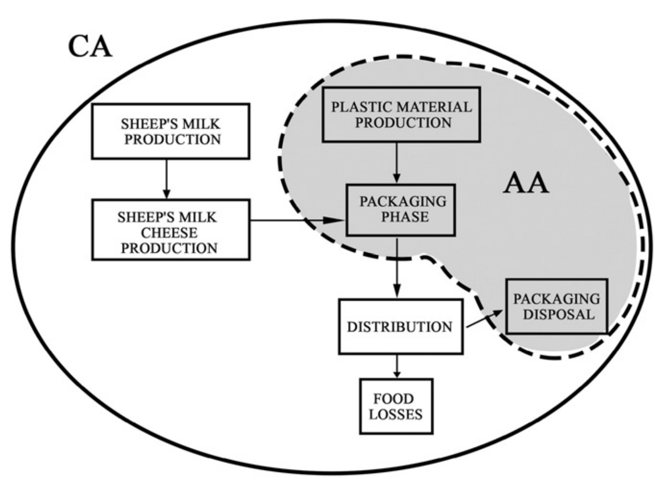

Fig. 1. System boundaries of the LCA methodology applying the two approaches, the Attributional approach (AA) and Consequential approach (CA)